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TITLE TESTING OF THE MARK 101 MAGNETIC FLUX COMPRESSION GENERATOR

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TESTING OF THE MARK 101 MAGNETIC FLUX COMPRESSION GENERATOR*

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ABSTRACT

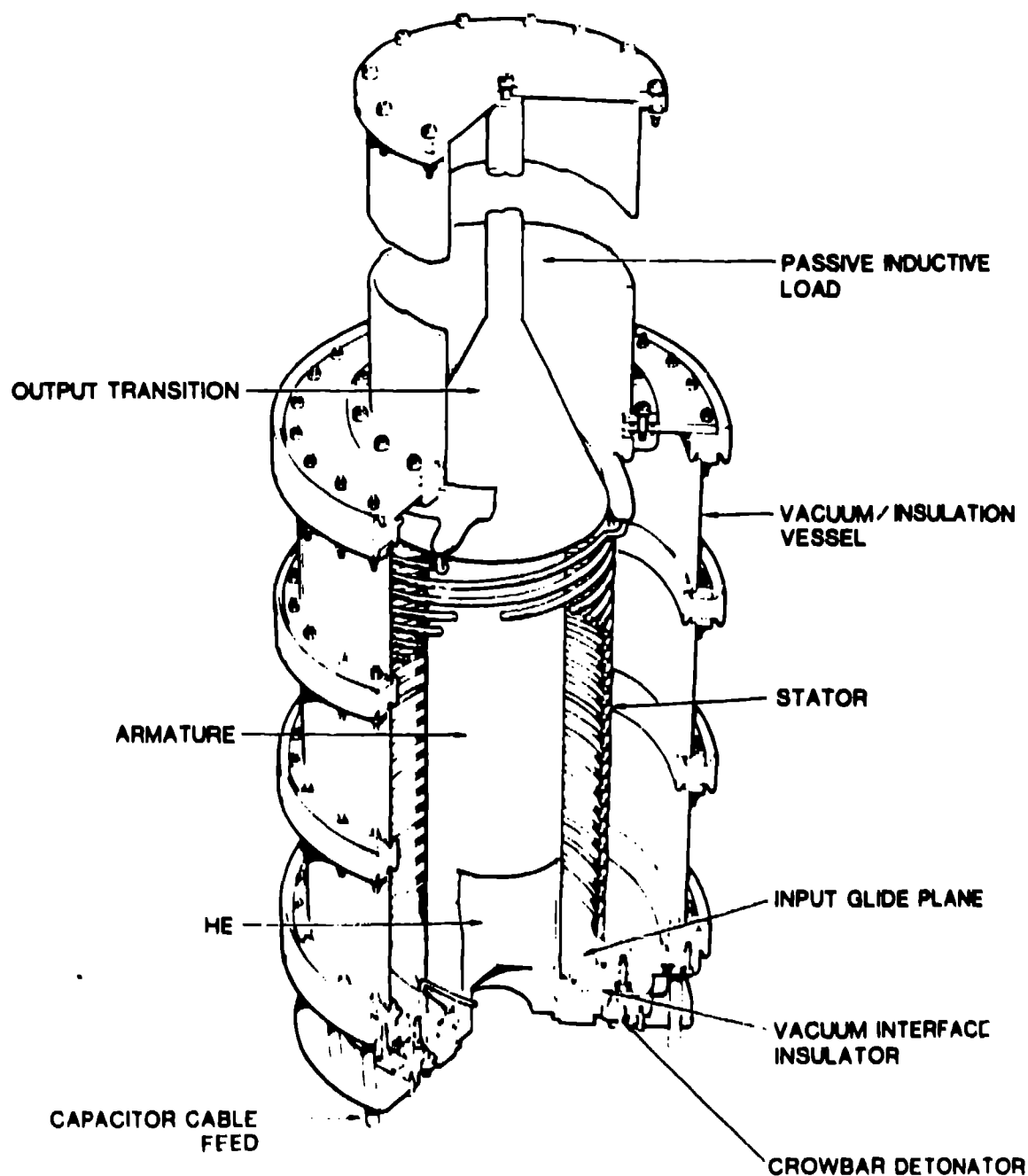
The Mark 101 explosive flux compression generator is a line-initiated, vacuum/magnetically insulated, helical generator. This device offered some unique challenges in transforming the theoretical design into a testable experiment. The two main reasons for this are that in theory an eight-turn, four-wire Mark 101 possesses a terminal dI/dt of $\sim 0.5 \Omega$ and operates with electric fields which are greater than the threshold for electron field emission. With this in mind, we designed an integral vacuum-jacket-generator configuration with a passive load inductance of $\leq 0.5 \mu H$. The generator contained $\sim 8 \mu H$ of initial inductance. The field emission required the stator to be entirely sealed within the vacuum jacket. The open, helical stator resulted in the presence of non-trivial leakage fields and voltages. To accommodate these fields, the vacuum chamber for the generator was segmented and axially insulated with rings of acrylic, similar to stacked-ring diodes. We made no attempt to break the azimuthal metal surfaces due to the physical difficulty this would incur. Diagnostics included an input current Rogowski loop, a load Rogowski loop, two dB/dt probes in the load, a Faraday fiber-optic current sensor, and two dB/dt probes in the region between the stator winding and the vacuum jacket to measure the leakage azimuthal and axial magnetic fields. The results of explosive tests are presented.

INTRODUCTION

The construction and testing of the Mark 101 explosive FCG (flux compression generator) has proven to be a challenge both mechanically and electrically. This FCG is a line-initiated, vacuum/magnetically insulated, helical generator. The design of this unit results in an initial inductance of $\sim 8 \mu H$ and a burnout L of $\sim 0.5 \Omega$ for the eight-turn, four-wire configuration. If an initial current of 313 kA is injected into the Mark 101, one expects an internal voltage of 0.9 MV, an external voltage of 470 kV, and a final current of 2.11 MA at peak voltage, assuming a passive load inductance of $0.5 \mu H$. Given these expected properties, the physical design must accommodate electric field strengths well in excess of the thresholds for gaseous electron avalanche and electron field emis-

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sion. The first threshold demands that the entire FCG must be evacuated to a reasonably hard vacuum. The presence of electron emission requires magnetic insulation since a hydrogenous insulation would lead to gas generation and electron avalanche within the operational time scales of interest, $>1 \mu s$. With an effective source impedance of $<5 \Omega$, this is easily achieved for the armature/stator region, but for turn-to-turn insulation within the stator, magnetic insulation is much more difficult to achieve. Our approach to these challenges was to design an integral vacuum-jacket/generator configuration with a passive inductive load for the initial developmental effort of this FCG design, Fig. 1.



MARK 101 GENERATOR

Figure 1.

MECHANICAL DESIGN

Along with the normal design questions one faces for new FCG designs, the Mark 101 offered four rather unique challenges. The first of these involved the input of the initial current into the FCG and the provision for a reliable crowbar. Since the entire operating volume must be evacuated, the more conventional approach of using sheet insulation and direct armature motion to the input glide plane to sever the insulation and provide crowbar, did not appear to be the optimal procedure. Rather, an input feed was designed with a vacuum insulator and a detonator-driven crowbar. In this manner, a vacuum interface could be obtained using structural materials while avoiding putting an insulation mass ahead of the armature. This mass would impede the outward expansion velocity at the input end of the FCG and could lead to trapping additional flux late in the generator run. While the input crowbar could be provided by simply allowing the armature to contact the glide plane, about 10 μ s after first motion, a more positive crowbar was provided by detonator-driven puncture of the input dielectric just before first armature movement.

In all FCG's, one must insure that the output end of the generator is closed last by the armature motion. In earlier helical FCG's this consideration was simply determined by initiating the explosive on the input end of the device. However, with the simultaneous initiation of the Mark 101, explicit design was required to ensure the proper closure. A precisely tapered stator would be very difficult to make. Since we have two-dimensional modeling capability, a taper was designed and machined into the armature. This provides a hydrodynamically formed taper for the appropriate closure geometry with respect to the intersection of the armature and stator, similar to the CN-II.²

Since the voltages are such that the presence of physical insulation could be counterproductive to maintaining magnetic insulation, a relatively hard vacuum was required throughout the operating volume of the FCG. Thus, a vacuum wall had to be placed outside of the stator winding. If this wall were conducting, the input current would preferentially flow through this wall, representing a lower inductance, rather than the stator winding. Also, with a ~50% open stator design, the leakage fields outside of the stator would not be trivial and could again drive currents in the vacuum wall. These considerations lead to an axially segmented vacuum chamber using acrylic rings to provide the electrical insulation, similar to a stacked-ring diode insulator geometry. No attempt was made to insulate against azimuthal currents because of the physical difficulty and expense this approach would entail.

The issue of stator support, stability, and positioning is only partially solved at this time. Since magnetic insulation is also required for turn-to-turn insulation, any approach to supporting and positioning the interleaved, helical coils must not intrude into the inter-turn spaces. At relatively low energy and voltage levels, an inductive/insulative support scheme has been used in which the stator is positioned and held in place with four acrylic supports which act as an exoskeleton for this structure. However, high energy operation will require the removal of all mechanical support structures. At this writing, we do not have an adequate solution for this part of the problem.

CAPACITOR BANK EXPERIMENTS

The capacitive discharge experiments were designed to test the input dielectric insulation package, the vacuum/dielectric interface, the integrity of the stator coil during the initial field loading, and the pos-

sibility of a V_{X} driven breakdown in the FCG output. These tests were accomplished by discharging a 600 kJ capacitor back into the assembly. Detonator switches are used to connect the low-inductance capacitor bank to the generator. Since the actuation time of these switches is ~ 1 ns, voltage doubling at the FCG input was expected because of the impedance mismatch at the cable/generator connection. Thus, a relatively inexpensive way to test both the dielectric insulation and the vacuum/insulator interface was to replace the armature with a solid aluminum cylinder and physically discharge the initial-current source into the generator. Simultaneously, such a discharge allows the integrity of the stator coil to be tested over the time scales of interest. This procedure lead to changing the attachments of the wire ends of the stator coil from soft solder to a silver-containing solder and pinned attachments scheme. Finally, within the original output of the Mark 101 the magnetic field was rotated from a predominately B_z magnetic field to a pure B_θ field within a length scale of < 1 cm. In some early experiments, we noted markings on the "ground" side of the FCG output that indicated that field emission may have occurred. By reshaping this part to have a strong helical component remaining in the current beyond the highest field region, the apparent emission was stopped. We speculate that the rapid field rotation in the output resulted in very large values of \dot{E} , which caused field emission of electrons at this critical point in the assembly.

EXPLOSIVE EXPERIMENTS

To date, the Mark 101 generator has been tested two times with an explosively-driven armature. The first of these preceeded our capacitive discharge experiments, so it differed significantly from the second explosive shot. This first experiment was initially loaded with 207 kA of current. Current multiplication began with the predicted first armature motion time and continued for ~ 7 μ s of the expected 20 μ s of generator run, Fig. 2. After this time, the \dot{I} fell to nearly zero, and the resulting maximum current was 241 kA. The gain for this shot was 1.16:1.

The second explosive test was performed very recently. This generator assembly employed all of the geometry changes incorporated since the first active generator shot. At least a partial list of modifications includes changes in the vacuum insulator, changing the glide plane angle from 5° to 9° for both the input and output ends of the FCG, a helical current carrying geometry at the generator output, and a modified stator wire attachment. Also, in an attempt to obtain a complete generator run of ~ 20 μ s duration, the initial current was reduced to 132 kA. However, this test resulted in an effective generator duration of ~ 8 μ s and a final current of 159 kA, Fig. 3. The gain in this case was 1.20:1.

Given the rather extensive differences between the two generators that have been tested, the surprising result is the extremely close similarity between these two experiments, Fig. 4. With an additional 1 μ s of effective run, the most recent test also demonstrated a corresponding increase in current of $\sim 4\%$ over the first Mark 101 fired. The disturbing note is that their respective \dot{I} performances are also very similar in nature. Obviously, future tests are planned.

CONCLUSIONS

Based on a theoretical design, presented at this conference, a new line-initiated spiral generator, the Mark 101, has been fabricated and subjected to initial tests. The physical design employs a detonator-driven crowbar, a hydrodynamically formed taper in the armature, a mag-

netically-insulated stator to attempt to achieve a working version of this FCG. To date, two explosive experiments have been fired. There are significant differences in key elements between the two physical assemblies tested. The most striking feature of these two FCG shots is their similarity, in spite of the differing experimental parameters. We have a puzzle to solve.

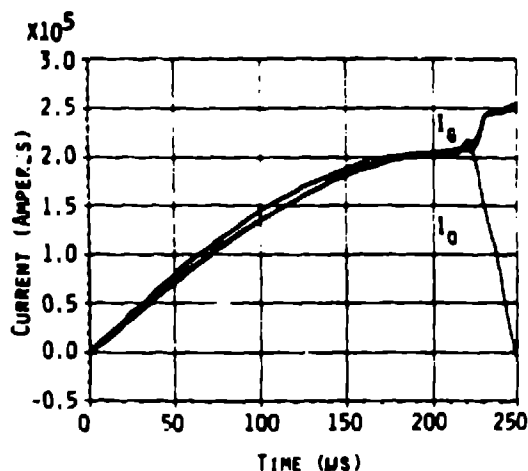


Figure 2.

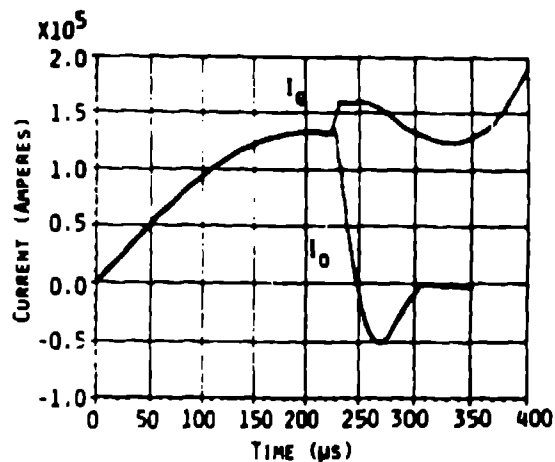


Figure 3.

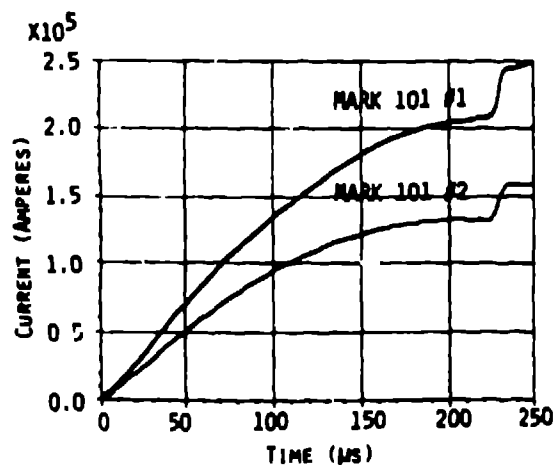


Figure 4.

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